IEC TR 62131-5

Edition 1.0 2015-08

TECHNICAL REPORT

colour inside

Environmental conditions – Vibration and shock of electrotechnical equipment – Part 5: Equipment during storage and handling

IEC TR 62131-5:2015-08(en)

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 19.040

ISBN 978-2-8322-2815-9

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CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

ENVIRONMENTAL CONDITIONS – VIBRATION AND SHOCK OF ELECTROTECHNICAL EQUIPMENT –

Part 5: Equipment during storage and handling

FOREWORD

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IEC TR 62131-5, which is a technical report, has been prepared by IEC technical committee 104: Environmental conditions, classification and methods of test.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
104/620A/DTR	104/639/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all the parts in the IEC 62131 series, under the general title *Environmental conditions – Vibration and shock of electrotechnical equipment*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this standard may be issued at a later date.

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ENVIRONMENTAL CONDITIONS – VIBRATION AND SHOCK OF ELECTROTECHNICAL EQUIPMENT –

Part 5: Equipment during storage and handling

1 Scope

IEC TR 62131-5, which is a technical report, reviews the available dynamic data relating to the handling of electrotechnical equipment. The intention is that from all the available data an environmental description will be generated and compared to that set out in the IEC 60721 series.

For each of the sources identified, the quality of the data is reviewed and checked for self consistency. The process used to undertake this check of data quality and that used to intrinsically categorize the various data sources is set out in IEC TR 62131-1.

This technical report primarily addresses data extracted from a number of different sources for which reasonable confidence exist in its quality and validity. The report also reviews some data for which the quality and validity cannot realistically be verified. These data are included to facilitate validation of information from other sources. The report clearly indicates when utilising information in this latter category.

This technical report addresses data from a number of data gathering exercises. The quantity and quality of data in these exercises varies considerably as does the range of conditions encompassed.

Not all of the data reviewed were made available in electronic form. To permit comparison to be made, in this assessment, a quantity of the original (non-electronic) data has been manually digitized.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60068 (all parts), *Environmental testing*

IEC 60068-2-27, *Environmental testing – Part 2-27: Tests – Test Ea and guidance: Shock*

IEC 60068-2-29[1], *Environmental testing – Part 2-29: Tests –Test Eb Bump*

IEC 60068-2-64, *Environmental testing – Part 2-64: Tests – Test Fh: Vibration, broadband random and guidance*

IEC 60721 (all parts), *Classification of environmental conditions*

IEC 60721-3-2:1997, *Classification of environmental conditions – Part 3: Classification of groups of environmental parameters and their severities – Section 2: Transportation*

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[1] Withdrawn and now incorporated into IEC 60068-2-27.

IEC TR 60721-4-2, *Classification of environmental conditions – Part 4-2: Guidance for the correlation and transformation of environmental condition classes of IEC 60721-3 to the environmental tests of IEC 60068 – Transportation*

IEC TR 62131-1, *Environmental conditions – Vibration and shock of electrotechnical equipment – Part 1: Process for validation of dynamic data*

IEC TR 62131-2, *Environmental conditions – Vibration and shock of electrotechnical equipment – Part 2: Equipment transported in fixed wing jet aircraft*

IEC TR 62131-3, *Environmental conditions – Vibration and shock of electrotechnical equipment – Part 3: Equipment transported in rail vehicles*

IEC TR 62131-4, *Environmental conditions – Vibration and shock of electrotechnical equipment – Part 4: Equipment transported in road vehicles*

3 Data source and quality

3.1 Container handling measurements by Hoppe and Gerock

Work by Hoppe and Gerock was under taken in the early 1970s and the resultant data are reproduced in a number of publications (see [1])[2].

Those data appear to have formed the basis for the road transportation severities in a number of national standards. Moreover, as far as can be identified, they are probably the original basis for the severities in IEC 600721-3-2. As the measured data also include a number of handling conditions, it is likely they were also considered in setting such severities. Although the measured data presented are limited, the scope of the measurements is sufficient to justify their inclusion here.

The Hoppe and Gerock work relating to handling, involved vibration and shock measurements on ISO containers at the container terminal, Hamburg/Burchardkai, during both in-yard transport and handling. The measurements included both 6 m (20 foot) and 12 m (40 foot) units when empty and loaded. Loaded 6 m and 12 m containers were also transferred onto a container train by means of a gantry crane. Dock side to ship measurements were made on loaded 6 m containers only.

Acceleration measurements were made at six locations within the containers; door end centre (in three orthogonal axes), door end right hand side (vertical only), centre of container (vertical only) and at the forward wall centre (vertical only). All six measurements were recorded simultaneously and continuously on an analogue FM recorder. The frequency range covered was 1 Hz to 1 250 Hz. All PSD analysis was undertaken using a 3 Hz frequency resolution and a record duration of 32 s.

The ISO containers used comprised steel framed structures with plywood walls with roofs reinforced with laminated fibreglass. The 6 m container was manufactured in 1969/70, it had an empty mass of 1 950 Kg and a loaded mass of 20 320 Kg. The 12 m containers were manufactured in 1970/71, had an empty mass of 3 490 Kg and a loaded mass of 30 480 Kg.

The container vibration measurements made during movement around the container terminal are summarised in Table 1. The measurements were found to contain predominant resonances associated with the suspension of the straddle or van carrier used to undertake the movements (typically at between 2 Hz to 3 Hz), the spreader used to support the container (6 Hz to 7 Hz)

2 Numbers in square brackets refer to the Bibliography.

and of the containers themselves (at around 160 Hz, 240 Hz and 400 Hz). The largest accelerations and displacements were consistently found to occur in the vertical direction and at the centre of the container. The largest derived displacement arose from carriage of the empty 6 m container at the maximum permissible speed. For the other container conditions the maximum speed was 20 km/h to 25 km/h.

The corresponding shock measurements when the containers were handled by the straddle or van carrier are summarized in Table 2. These include peak amplitudes occurring during pick up, set down on to the ground as well as set down on to another container. Again the largest accelerations were consistently found to occur in the vertical direction and at the centre of the container. The largest shocks were noted to occur during engagement and disengagement of the spreader.

The Hoppe and Gerock work also included measurements picking up and setting down containers on to rail vehicles (summarized in Table 3) and during transfer on to ships (summarized in Table 4).

The shock measurements are all presented in terms of peak acceleration amplitude and shock duration. No time histories are presented so the method used for the derivation of shock duration cannot be verified. Only one Shock Response Spectra (SRS) for handling is presented and its origins are unclear.

Although the information in this report is limited the quality of the information is reasonable and meets the required validation criteria for data quality (single data item).

3.2 Intermodal container handling by Association of American Railroads

This relatively recent (1991) work from the Association of American Railroads (see [2]) concerns the measurement and analysis of vibration and shock conditions experienced by standard ISO containers when transported by both rail and road. The objective was primarily to establish the relationship between the vibration and shock conditions experienced during rail and road movements. However, the work also includes shock and vibration measurements that occurred during handling. The data source relates almost entirely to ISO containers on the US and Canadian rail system.

The report indicates that the handling measurements utilized a self contained recorder. The recorder was programmed to record data in 7,7 sblocks of data when a threshold of 0,1 g was exceeded for more than 3,9 ms. These recorder settings were selected in an attempt to collect data virtuously continuously. The sample rate was 256 samples per second (sps) filtered at 30 Hz with a Butterworth low pass filter. The pre-programmable data recorders housed three orthogonal accelerometers capable of DC measurement (using piezoresistive accelerometers) in the vehicle fore/aft, lateral and vertical axes.

Measurements were made on a trailer carrying a 12 m (40 foot) ISO container, whilst it was loaded on and off rail cars. The loading and unloading adopted both overhead crane and a sideloader. The peak acceleration levels from these operations are summarized in Table 5 and the associated acceleration power spectral densities are shown in Figures 1 and 2.

The information in this report is limited to a trailer carrying 12 m (40 foot) ISO containers. It may also be specific to the US and Canadian rail systems. However, the quality of the information is good and meets the required validation criteria for data quality (single data item).

3.3 Intermodal container handling at Swedish container terminal

These very recent measurements (2007) were undertaken by Mariterm AB in conjunction with Helsingborgs container port (see [3]). The measurements relate to the handling of a 12 m (40 foot) empty container at the Helsingborgs container port.

The measurements were acquired using a data acquisition DT9816 recorder; this allowed measurement of 6 channels (2 × three orthogonal axes) of acceleration measurements. The digital recorder comprised a 12 bit ADC sampling at 1 500 sps. Four channels of measurements were low pass filtered at 370 Hz (one tri-axial and the fore/aft channel of the other) and two channels at 500 Hz. The accelerometers were positioned along the centre line of the container, on the floor and around 6 m apart. Although, the measurement axis of each channel is known, the specific identification of the tri-axial accelerometer is unclear. For this reason, the measurements are designated as from transducer groups 1 and 2.

The recorder measurement range was set to 10 g, which in comparison to other exercises, is somewhat low. Moreover, a few of the shocks, specifically in the vertical axis, appear to exceed this measurement range.

Measurements were made during handling of the container by a dockside container crane, movement by a container tug, handling by a container crane and handling by a straddle carrier. For each condition several separate measurement runs were made. Some attempt appears to have been made at making the measurements during different severities of handling conditions.

The report [3] supplies both sample time histories (albeit encompassing the entire record, typically 10 min to 20 min) and summary peak acceleration data along with approximate duration of the shock event. However, in addition to the report, the electronic measured data were also made available.

From the electronic data, summary information on the vibration severities are assembled in Table 6 and summary information of the highest shocks measured is presented in Table 7. Envelopes of the vibration acceleration power spectral densities, from each of the four handling conditions and for each axis, are presented in Figures 3 to 5. Amplitude probability densities, again for each of the four handling conditions and for each axis, are presented in Figures 6 to 8. Shock response spectra are presented in Figures 9 to 11.

Although the information in the hardcopy report is limited, the quality of the electronic information is good and meets the required validation criteria for data quality (single data item).

3.4 Handling of air cargo pallet at Stockholm and New York airports

The Swedish Packaging Research Institute reported a field study of loadings on an air cargo pallet in 1988 (see [4]). The measurements were made both on board a Boeing 747 Combi (freight and passenger) aircraft and also during cargo handling operations at both Stockholm airport (Arlanda) and New York (John F. Kennedy Airport). Shock and vibration acting on the cargo during handling were measured and analysed.

A tri-axial accelerometer was mounted on the pallet with double-sided tape and was placed approximately midway along the length of the pallet, about 0,5 m from the pallet edge. A fourth, separate, vertical accelerometer was mounted near the end of the pallet, approximately 0,5 m from the corner. The transducers were not mounted on the cargo in an attempt to establish acceleration measurements sensibly independent of cargo type. Nevertheless, the pallet loads chosen were 'typical'. During the outward stages (stages 1 to 3) the weight of the test pallet was 1 470 kg and during the return journey (stages 4 and 5) the weight was 2 550 kg. The measurement encompassed five stages:

– Stage 1 Arlanda terminal to aircraft, pallet weight 1 470 kg;
– Stage 2 Arlanda movement at aircraft, pallet weight 1 470 kg;
– Stage 3 JFK aircraft to terminal, pallet weight 1 470 kg;
– Stage 4 JFK terminal to aircraft, pallet weight 2 550 kg;
– Stage 5 JFK loading on aircraft, pallet weight 2 550 kg.

The field data recorded during the trip have been computer analysed in the time and frequency domains. The frequency domain analysis was carried out using both conventional spectral analysis and autoregressive modelling techniques. The sampling frequency chosen was 100 Hz and the signal was low-pass filtered at 31,5 Hz. The number of records, each spanning 256 samples, depended on the conditions under investigation. However, this was limited to 350 records, i.e. a sampling time of no more than 15 min. The window mostly used for the frequency analysis was the Blackman window. For the analysis using autoregressive modelling for the spectral estimation, the Hamming window was used.

A summary of the recorded extreme handling shock values and r.m.s. values are given in Table 8. A summary of the corresponding vibration data is shown in Table 9. The vibration data comprise acceleration levels (g) exceeded for 1 % of the time of the trial. Vibration spectra for each stage are shown in Figures 12 and 13 for the vertical and transverse axes respectively.

3.5 Forklift handling

This 1975 measurement exercise (see [5]) was undertaken by M.B. Gens at the Sandia Laboratories in the US adopted a common payload and four different size forklift trucks. Although a little old these measurements are the basis for conditions in several standards.

The measurement exercise addressed the transient conditions arising from traversing a test track made up of paved and unpaved areas. The paved areas included asphalt streets with manhole covers and metal utility covers as well as concrete aprons and driveways. The paved surfaces included both new and smooth surfaces as well as old and deteriorated surfaces. The unpaved areas were not intended as a driving surface and included steps of up to 25 mm. Experienced drivers were used, each instructed to travel at highest speed possible consistent with retaining the payload. In general, speeds were reported to be less than 10 mph (16 km/h) and mostly below 5 mph (8 km/h).

The measurements were made both on a pallet carrying a payload and the payload itself. The report indicates the payload as having a mass of 1 000 lb (500 Kg). The four forklift trucks were characterized as

– 1 000 kg (2 000 lb) capacity, electric powered and solid tyres;
– 1 500 kg (3 000 lb) capacity, petrol powered and pneumatic tyres;
– 2 000 kg (4 000 lb) capacity, petrol powered and pneumatic tyres;
– 3 500 kg (7 000 lb) capacity, petrol powered and pneumatic tyres.

The measurements were made using two groups of orthogonally orientated transducers; one group selected and set to measure accelerations up to 50 g peak-to-peak, the other to 10 g peak-to-peak. Tri-axial measurements from both groups were made at two locations; one close to the input from the forks and the other on the skin of the payload. All measurements were recorded on an FM tape recorder.

The 5 Hz band pass analysis of the data elicited the conclusion that no steady state continuous randomly distributed excitation was present in the forklift environment. Discrete excitations, on the other hand were prevalent. A total of 49 vibration spectra (from all four forklift trucks) were combined to allow plots of mean, mean plus three standard deviations as well an envelope of maximum response. The responses for the pallet measurements (effectively the excitations applied to the payload) are shown in Figures 14 to 16 for the vertical, lateral and axial axes respectively. The envelopes of largest shock response spectra for each of the four forklift trucks are shown in Figures 17 to 20.

3.6 Movement of unsuspended trolleys

This very recent (2009) measurement exercise (see [6]) was undertaken, by Drager Medical, to determine the vibration and shock conditions arising from the movement of medical trolleys over flooring typically occurring within modern building and outside in car park type surfaces. The three trolleys have small, unsuspended castor type wheels which are common to many

items of modern electro-technical equipment. They are also typical of handling trolleys commonly used to move small packages on and off trucks and around warehouses. All the movement occurred at walking speed.

The measurements were made on three different medical devices as set out below. In each case the tri-axial acceleration vibration measurement were made on the support system, just above the wheels:

– small trolley – A small medical ventilator, mass 22,5 kg, castors 100 mm diameter, castor surface PA6 of hardness Shore A 80;
– medium trolley – Anaesthetic workstation, mass 147 kg, castors 125 mm diameter, castor surface polyurethane of hardness Shore D 40;
– large trolley – Intensive care ventilator, mass 54 kg, castors 125 mm diameter, castor surface polyurethane of hardness Shore D 40.

The intended velocity of the movements was 0,5 m/s although the real velocity appears to have varied between 0,5 m/s and 0,7 m/s. Movement was in the X (axial) axis with the Z axis vertical. The typical 5 surface types traversed were

- composite stone,
- granite plates 70 cm × 70 cm,
- pvc floor 60 cm × 60 cm at 0,5 m/s and 0,7 m/s,
- asphalt light grey,
- asphalt rough.

The transducers and measurement system are indicated as within calibration. The digital recorder sample rate was 8 192 sps and the remainder of the measurement chain was capable of measurements of at least 3 kHz. The recorder utilized a 16 bit ADC, an anti-aliasing filter of 3,2 kHz. The measurement record lengths varied between 1 min and 3 min although 120 s was commonly achieved. In this case the measured data and all the analysis are available digitally.

Shown in Figures 21 to 29 are the vibration severities for each of the three axes for each of the three devices. A summary of the corresponding overall acceleration root mean square values are presented in Table 10. Amplitude Probability Density (APD) values for the device which experienced the most severe conditions (the small medical ventilator) are show in Figures 30 to 32. Corresponding Shock Response Spectra (SRS) for the same device are shown in Figures 33 to 35.

3.7 Supplementary data

The data collection exercises which preceded this particular assessment attempted to supplement the data with any relevant sets of information, arising from reputable sources, but for which the data quality could not be adequately verified. Although no additional sources were identified, a SRETS study (see [7]) undertaken during 1998 reviewed the types and occurrences of damage that occur as a result of transportation and particularly that identified during handling related to transportation. Although that report (see [8]) contains no specific information on the mechanical environments occurring during handling, it does give a good review of the different types of damage a range of items may experience during handling.

4 Intra data source comparison

4.1 General

The purpose of the following subclauses is to review each data source for self consistency. The process for evaluating the vibration data takes into account the variations arising from the different methods of handling.

4.2 Container handling measurements by Hoppe and Gerock

Although the extent of the vibration information, tabulated in the Hoppe and Gerock report, is relatively limited it does, with one exception, appear reasonably consistent. The acceleration amplitudes are quite low, possibly giving rise to concerns over measurement accuracy. The derived displacements are relatively high, for the low acceleration levels, suggesting low frequency excitations (which are confirmed in the report). With that said, the report does not make clear the method used for deriving displacements from the acceleration measurements. The concern is that high displacements can arise if this is not undertaken appropriately. The distribution of amplitudes between full and empty containers, as well as between axes, is largely as would be expected. The one value that is out of line with the remainder is the vertical measurement on empty containers. The acceleration amplitude indicated is more than double any other tabulated value and the listed peak displacement is four times greater than any other. The occurrence of this condition is explained in the report as due to high movement speeds. The indicated peak displacement is essentially the same as the largest equivalent drop height suggested from consideration of the shocks.

The tabulated handling impact acceleration amplitude values, presented in the Hoppe and Gerock report, indicate an underlying trend. That is smaller empty container generally generate the worst case conditions whilst the largest loaded containers generally result in lower impact acceleration amplitudes. This is entirely as would be expected.

The shock data quotes acceleration amplitudes as well as durations. As a consequence of the different approaches used, the validity of tabulated shock durations, without a description of how they were derived, is always questionable. A verification exercise has been undertaken, which assumes the shocks are a result of impacts between two elastic bodies. The exercise indicates that the accelerations and the derived velocities follow a realistic and consistent relationship, Figures 36 and 37 refer respectively. Only a few values fall outside the main trend but even those are only to an extent expected from measured data. The largest indicated velocity change is 0,6 m/s with the majority of impacts occurring below 0,4 m/s. The values suggest that size of container or its loaded state makes no underlying difference to the velocity. The largest equivalent drop height, derived from the velocities, is a little less than 19 mm.

The Hoppe and Gerock report supplies only a single shock response spectrum for the handling impacts and this is marked as 'typical'. Nevertheless, the shape of the shock response spectra is typical of that for short duration impacts of the type indicated by the tabulated values.

Overall, the Hoppe and Gerock data appears self-consistent, showing trends and values that are largely within expectations. The data meets the required validation criteria for quality against the intra data source comparison criteria.

4.3 Intermodal container handling by Association of American Railroads

The handling information presented by the Association of American Railroads report is quite limited and the handling measurements clearly were not the primary objective. The shock values appear reasonable consistent although, given the limited information, no useful trends can be discerned. The relationship between axes appears reasonable and as would be expected. The frequency spectra indicate quite low frequency content from both handling devices. The main concern with this data is that it is sampled at 256 sps and low pass filtered at 30 Hz which is quite low for shock measurements. This may be limiting the peak amplitudes measured. Also as no shock durations are indicated, the equivalent velocity and displacement cannot be derived.

Although the data, in the Association of American Railroads report, meets the required validation criteria for quality against the intra data source comparison criteria, it is limited in both extent and range. The Association of American Railroads report supplies shock amplitudes but not the corresponding durations. As a consequence they cannot be credibly compared with other data and have only limited usefulness in the comparison with existing environmental descriptions addressed hereinafter.